

Application and Testing of GPFARM: A Farm and Ranch Decision Support System for Evaluating Economic and Environmental Sustainability of Agricultural Enterprises

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Abstract

GPFARM is a decision support system (DSS) software package currently being developed by the USDA-ARS Great Plains Systems Research Unit. The primary goal of the Great Plains Framework for Agricultural Resource Management (GPFARM) DSS is to provide farmers and ranchers with a strategic tool to evaluate long-term effects of management and resource allocation on economic and environmental sustainability. The software program incorporates three stand-alone components: a science simulation model, an economic analysis tool, and a WWW-based agricultural information system. The simulation model can be run with either historical or generated climate data. The economic analysis tool calculates costs and returns from either model simulation output or actual farm/ranch enterprise data. Evaluating and testing GPFARM is being accomplished in many ways and on various levels. This paper focuses on GPFARM on-farm/ranch testing in collaboration with producers in three states. Two levels of on-farm testing are being performed in order to validate GPFARM. In the first, referred to as enterprise testing, detailed whole farm or ranch enterprise data are collected on resources (e.g., soils), management practices, and economics. The information is entered into GPFARM, simulations are run, and system output is evaluated by cooperators. The second level of testing, referred to as scientific testing, involves collecting similar information as in enterprise testing. However, soil sampling and analysis are conducted at planting and harvest on select fields. In addition, crop yields (determined by yield monitors) are analyzed, and on-site precipitation is collected during the growing season. We conclude this paper with valuable lessons learned in working with cooperators and conducting on-farm/ranch testing of the GPFARM DSS.

INTRODUCTION

Successful farming and ranching requires both economic and environmental sustainability. Farmers and ranchers need tools to help them balance production, economic, and environmental issues. Both simulation modeling programs and decision support systems (DSS) are tools that potentially can assist producers in creating this optimum balance. The need for decision support tools by producers dates back at least 20 years and was emphasized at a regional symposium entitled "Sustainable Agriculture for the Great Plains" (Hanson et al., 1991), and was verified in a 1995 survey conducted of nearly one thousand agricultural producers and consultants (Ascough et al., 1999; Hoag et al., 1999).

Application of models and decision support systems is generally approached in two ways: either the model developers apply the model/DSS for a given situation and report the results, or the model/DSS is utilized directly by farmers or other end users to address situations of their concern. GPFARM is a DSS that is intended to be used and applied primarily by farmers, ranchers, and agricultural consultants to aid in strategic planning of whole farms and ranches. Other users are funding institutions, action agencies, and

scientists. Whole-enterprise planning is approached by analyzing how each land use parcel, or management unit (MU), within the enterprise can best be utilized by simulating the production and yield, economics, and environmental impacts of the MU as affected by soil, climate, and management practices. GPFARM is designed to let the user change any farmer- or rancher-controlled management practice and view the effects of the change on a variety of outputs. GPFARM provides opportunities to test alternative management practices on the computer before applying the changes in the field or pasture. Perhaps equally important is that the producer or consultant can use these what-if strategic planning exercises in collaboration with bank/financial firms to satisfy loan requirements.

The objectives of this paper are to provide a brief overview of the GPFARM DSS, and discuss results and lessons learned from GPFARM on-farm/ranch testing and collaboration with producers.

OVERVIEW OF GPFARM

GPFARM encompasses three stand-alone components that, when used in conjunction with other components (e.g., environmental impacts assessment module, GIS spatial visualization module, and multicriteria decision support module), provide a unique decision support tool for farmers and ranchers. The first stand-alone component is a computer model that simulates crop and animal (beef cattle) growth, soil water movement, nitrogen cycling and transport, weed growth, pesticide transport, and water/wind erosion. The second component is an economic analysis tool, capable of taking yield and cost data from the simulation model or directly from user input and providing a detailed economic analysis. The third stand-alone component is an agricultural information system. This WWW-based system contains links to information on crops and crop pests, livestock and livestock pests, agricultural chemicals, and other agriculture-related topics. The information system is complete and available to consumers. The simulation model and economic analysis tools are still in the testing and validation phase.

Science Simulation Model

GPFARM consists of modules within an object-oriented framework (Shaffer et al., 2000). The main modules of GPFARM are briefly discussed below. Some modules were incorporated from existing agricultural water quality models and modified to varying degrees, while other modules were developed specifically for the GPFARM DSS.

- Crop growth module. This module is based on the crop growth module of the WEPP simulation model (Arnold et al., 1995), which is a modified version of the EPIC crop growth submodel (Williams et al., 1989). The module uses concepts of daily accumulated heat units; harvest index for partitioning grain yield; Monteith's approach for determining potential biomass (Monteith, 1977); and water, N, and temperature stress adjustments to daily growth. Crop/variety-specific parameters are kept in a default database to simulate daily growth. Currently, GPFARM is parameterized for winter wheat, maize, sunflower, sorghum, proso millet, and foxtail/hay millet.
- Rangeland system module. This is a new module that simulates pasture and beef cattle dynamics. Daily production of five plant functional groups is simulated: cool-season grasses (C₃), warm-season grasses (C₄), legumes, forbs, and shrubs. All functional groups respond to soil moisture and temperature. Herd dynamics and growth are simulated for five classes of animals: mature cows, heifers, female and male calves, and bulls. Bulls are managed as a second herd, and forage consumption and daily weight gain or loss are estimated by the model. The percent of replacement heifers and culls retained or sold each year are user-defined. Calf crop is determined by the number of bulls and the duration of time that bulls are with open cows. Cattle nutritional needs can be met by either supplemental feed using a least-cost ration approach or forage from the pasture. The user controls all management activities such as calving dates, rotation among pastures, and the buy/sell dates of livestock.
- Weed module. This is a newly developed module. Both the effects of weed pressure

levels on final crop yield and the weed population dynamics as affected by management and competing crop are simulated. Fifteen annual weed species (and also herbicide resistant forms, if known) are parameterized in default databases for the weed-crop interactions.

- C and N cycling module. This module is based on the NLEAP model (Shaffer et al., 1991). Submodules simulate soil C and N cycling and surface residue. Residues decay to form soil organic matter and mineralization, immobilization, nitrification, ammonia volatilization, and denitrification are simulated.
- Water balance module. This module is a simplification of the RZWQM water balance routines (Ahuja et al., 2000) and uses a coarser time step between precipitation events to determine soil water fluxes. The daily water budget and chemical balance module simulates the soil water content of each soil layer changes to the initial soil water content based on precipitation, surface runoff, ET, and snow water content. Soil hydraulic properties are adjusted due to tillage, residue cover, soil crust, and soil macropore presence. Upward flux from water tables and restrictive soil layers on water and chemical leaching is simulated.
- Water erosion module. For cropland, the water erosion module is based on the CREAMS erosion model (Knisel, 1980). Characteristics of rainfall and runoff factors for each storm are used to simulate particle detachment and sediment transport. For rangelands, the module is based on the work of Lane et al. (1988) and uses distributed canopy and ground cover down the hillslope to estimate management effects on soil erosion. A quasi-steady state is assumed and sediment movement downslope obeys continuity of mass.
- Environmental impacts module. In this module, nitrate and pesticides are co-transported with water with possible retardation from soil adsorption.

Economic Model

The stand-alone economics model was developed specifically for GPFARM in collaboration with agricultural economists at Colorado State University. It is intended to capture all costs and returns of crop and rangeland production (by MU, field, or for the whole farm/ranch). Farm/ranch enterprise budgeting procedures are completed by the user and merged with other user-supplied information to calculate gross income, total costs, and net returns. Users can perform a breakeven analysis (Figure 1) or view enterprise budget reports that show costs vs. returns on the whole enterprise, individual MU or crop, or by year. Detailed economic analysis also is available for machine, labor, financial, animal, and materials input.

EVALUATING GPFARM

GPFARM is currently being evaluated and tested in five ways: 1) on-farm/ranch testing; 2) research plot or scientific testing; 3) general evaluation by producers and scientists (i.e., expert opinion evaluation); 4) sensitivity analysis; and 5) trend analysis. The remainder of this paper focuses on GPFARM on-farm/ranch testing and lessons learned from producer collaboration.

GPFARM is being designed for initial release in portions of four states (Figure 2), with the majority of cooperators located in Colorado. Three on-ranch cooperators were identified and are located near Lander, Wyoming; and Nunn and Westcliffe, Colorado. Five on-farm cooperators were identified and are located near Grant, Nebraska; and Sterling, Stratton, Haxtun, and Akron, Colorado. GPFARM enterprise testing involves meeting with a cooperator several times to capture information on the specifics of the cooperator's operation. The data collected includes: legal descriptions of all fields, crop and livestock rotations for all fields, equipment data, planting dates, chemical usage, yields, herd information, supplement usage, range management, forage production, livestock events, and sales information. The information is then entered into GPFARM by the field team, simulations are run, and the results presented to the cooperator for their expert evaluation on output accuracy and usefulness.

Information needed to validate the science simulation model is also collected at cooperator farms. At Sterling and Stratton, Colorado very detailed on-farm soil, weather, and plant data have been collected similar to research plot experiments. At other cooperator sites, less detailed data are collected including: soil sampling for nitrate N, water, and organic matter levels; mapping of the soil series; precipitation data; and yield monitoring using GPS technology.

RESULTS

At Sterling and Stratton, Colorado various dryland, no-tillage crop rotations have been studied for over ten years. Preliminary simulation results analyzing these experiments are shown in Figure 3, although science model modifications continue to be made during the testing phase, which will alter the results presented herein.

For other cooperator sites, comparison of simulated versus observed yields provided mixed results. Long-term average winter wheat yields from GPFARM simulations were close to cooperator expert opinions of yields from their fields. Simulated irrigated corn varied only slightly from year to year and was very close (< 10 bu/ac) to the long-term average for the irrigated corn field. Simulated yields of dry-land corn were consistently and significantly lower than historical yields when averaged over time. These and other results emphasize that crop parameter re-estimation is necessary following significant model changes that have occurred since the last time parameter estimation occurred.

The most encouraging results have been those produced by the economic analysis tool. Economic analysis results (not shown here) matched published estimates quite well, i.e., informal evaluation indicated that we are able to capture farm enterprise economics to within about \$1 US per acre. Producers have been extremely satisfied with the economic analysis tool.

LESSONS LEARNED FROM COLLABORATORS AND ON-FARM/RANCH TESTING

Creating a user interface acceptable to farmers, ranchers, and consultants is critical to the success of a DSS such as GPFARM. One challenge has been how to develop an interface that allows the user to “instantaneously” set up the model/DSS to run, but still contain enough information to be able to produce useful and accurate results. For the GPFARM DSS, parameterization of plant, soil, climate, etc. components must be performed for the user, and all other inputs minimized as much as possible. Creating a “simple yet robust” user interface and corresponding relational databases has required constant interaction with collaborators from the beginning of the GPFARM project. As new producers interact with the interface, invariably changes must be made. In part, these changes are due to further examination of the interface by a new collaborator, but a primary reason for interface modifications is that each producer has slightly different operations and needs and their interests change with time. Recent modifications requested for the interface relate to the ease of setting up GPFARM or analyzing the simulation results (e.g., easier access to the soil databases, easier equipment selection, providing custom rates for farming operations, spatial visualization of output results, linking the climate database with GIS, and allowing the user to run either the science simulation model or economic analysis as a stand-alone tool rather than having to run both in all instances).

Other lessons learned have caused greater concern. Despite having clear support from producers when starting this project on several aspects, including the need for a strategic (long-term) planning tool and the requirement that crop yields must be affected by weed pressure, current cooperators have expressed a greater concern for the development of a tactical (real-time) decision aid. Some of this is explained by the specific situation of the cooperators, which underscores the importance of not only having user input from the beginning of the project, but also having adequate representation of the entire producer population. Producers are as diverse in their views and needs as any other group of individuals.

Another concern is that if producers are asked how accurate crop yield predictions must be, the typical response is “within about 10%.” The current state-of-the-art of crop growth simulation models is that, even with accurate determination of inputs and crop/variety parameters and no biotic stresses (i.e., weeds, pests, and disease), it is extremely difficult to achieve the “10% requirement” because we are unable to adequately address all the spatial and temporal variability inherent in the soils, climate, and management practices. If the temporal yield patterns and the overall yields appear reasonable, this is usually satisfactory to the producers. It is simple to correct the yield predictions in the economic analysis tool so that a realistic economic analysis is obtained.

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Figures

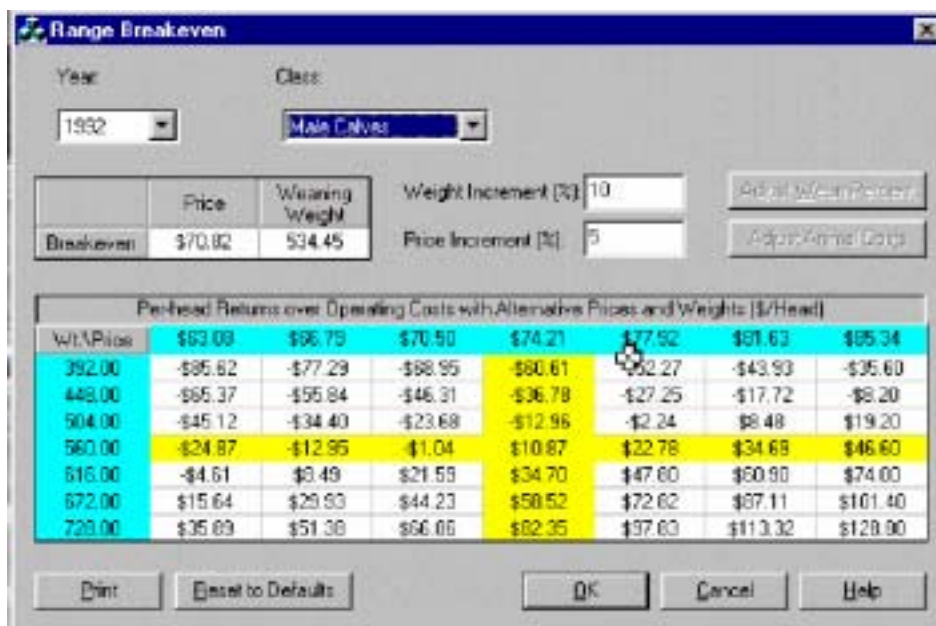


Fig. 1. Example of GPFARM breakeven analysis economic output for male calves.

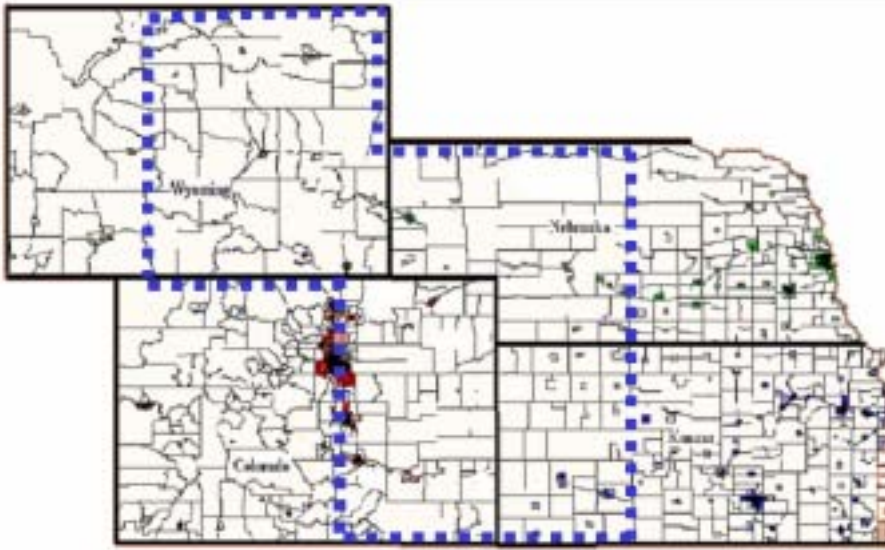


Fig. 2. Geographic area for initial delivery area of GPFARM within Colorado, Wyoming, Nebraska, and Kansas is denoted by dotted line.